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# "CREW SYSTEMS DEVELOPMENT IN SUPPORT OF MANNED SPACE FLIGHT"


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## I. Introduction

The successful flight of Astronaut L. Gordon Cooper completed the first phase of the U.S. Man in Space projects. The Project Mercury Spacecraft was originally developed for a basic three-orbit mission with the capability of a possible extension to an 18-orbit flight. These flight goals were all accomplished without a major mishap and the astronauts have proven that man has a place in space. It is a recognized fact that without the astronaut onboard, recovery of at least two of the Mercury spacecraft would not have been accomplished.

The use of man in follow-on flight projects is being expanded with mission extension. Progressing from the Mercury Spacecraft with automatic and manual systems in which the astronauts served as backups to these systems to the Apollo flights, prime control will be provided by the crew. This expanding and critical role of the flight crewmen provides an increasing responsibility and a more complex challenge to the bioengineer, physiologist, and a physician to provide satisfactory life support and protective systems and to establish a fundamental understanding of crew physiology and performance in space flight.

This paper presents some of the crew systems development problems encountered in the Mercury flights. Systems such as the environmental control systems and its thermal control problems are described. The food, bioinstrumentation and atmospheric instrumentation systems flown in Cooper's flight are briefly discussed.

The physiological research programs which are being conducted to provide design information for the Gemini and Apollo spacecraft subsystems are outlined. The feeding concepts being employed for the Gemini spacecraft are described.

Also briefly described are medical research efforts currently underway to provide a better understanding of the physiological aspects of long term space flight.

## II. Crew Systems Development

### Environmental Control Systems

The Mercury environmental control systems have been previously described in detail (1). Therefore, only a brief summary is presented here. In Project Mercury, a semi-closed-type environmental control system, as shown in Figure 1, was selected to conserve oxygen and thus reduce system weight. The astronaut wore a full pressure suit at all times to provide protection in the event of cabin decompression. Both the cabin and suit were maintained at a pressure of 5 psia with oxygen. The cabin system basically provided a method for the control of cabin pressure between 4.1 and 5.1 psia and for the thermal control required to maintain onboard system temperatures. The space suit circuit provided a continuous flow of oxygen in a recirculating loop. This oxygen was distributed throughout the space suit for body ventilation and breathing purposes. The metabolic products such as heat, carbon dioxide, odors, and water vapor were removed or controlled in this loop. Several automatic modes of pressurization operation were provided. In the Mercury flights the environmental control system performed satisfactorily except for thermal control variations.

The space suit circuit thermal control was maintained by utilizing a water boiler type heat exchanger similar to that depicted in figure 2. The quantity of cooling water was metered manually by the astronaut into the heat exchanger. Boiling of this water was effected by the vacuum of space, and in this way the suit circuit gas was cooled. In the first two manned Mercury orbital flights, the astronaut was provided a sensor/warning signal intended to indicate when excessive water flowed into the heat exchanger. It was found that the warning signal followed rather than preceded freezing of water in the heat exchanger and exhaust ducts, and therefore suit temperature control was not satisfactory. As a result, a laboratory study was made on ice formation in the heat exchanger. It was found that relocation of the thermal sensor would improve water flow to the heat exchanger. In Astronaut Schirra's flight, a temperature measurement within the heat exchanger was displayed. Suit temperature thermal levels were satisfactorily controlled. The suit thermal control problems were, however, again encountered in Astronaut Cooper's flight. It is felt that the control of the extremely small water flows into the heat exchanger sufficient to remove the variable heat load produced by the astronaut was too sensitive and delicate for manual control. Changes in metabolic heat loads while sleeping necessitated a reduction in water flow while increased work rates required increased water flow. In the Gemini and Apollo environmental control systems, the thermal regulation of suit temperatures will be semiautomatically controlled.

## Food Provisions

Food provisions were included in the Mercury flights primarily as a research experiment to determine the astronauts' ability to consume solids, paste-type foods and liquids under zero gravity. Figure 3 shows the typical foods flown in the first three manned orbital flights. These items consisted of collapsible tubes of puree foods such as meats, fruit and vegetables, malted milk tablets, and bite-size high-calorie cubes in a dispenser. In these flights, the astronauts consumed part or all of these foods without encountering problems of ingestion or swallowing. Some of the solid-type foods were found to crumble causing particles to float in the cabin. In Astronaut Cooper's flight, experimental freeze-dried foods (fig. 4) being developed for the Gemini flight project were utilized. In addition, bite-sized solids were provided with an edible coating which prevented the crumbling previously encountered. Problems were encountered in rehydrating the freeze-dried foods. The normal drinking water nozzle in Cooper's spacecraft was modified to mate with the freeze-dried food packages and water was delivered under pressure. During the flight, the water delivery system developed a leak in a fitting and sufficient water pressure was not available to force water into the freeze-dried food packages. Also, some water droplets floated free of the nozzle when separated from the food packages. As a result of this flight experience, redesign of the Gemini water nozzle is being accomplished to insure that once the nozzle is turned off and disconnected, free water will not be present to float away into the cabin.

Freeze-dried foods have been selected for use in the Gemini spacecraft. The basic foodstuff is frozen and at the same time the pressure is reduced removing the water. This dehydration technique of food preservation is applicable to meats, vegetables, fruits, juices, and most common beverages. This process permits long term storage of the food at room temperatures and preserves the taste and nutrient value. The food, packaged in single-meal form, is reconstituted by the addition of water.

Packets are easily stored in selected locations in the spacecraft. Partially-used portions are resealed and stored for further use or disposal.

A day's ration of a varied menu using typical breakfast, lunch, and dinner foods provides 2,500 cal./day, weighs 1.3 pounds, and is stored in approximately 100 cubic inches. A comparison between an early Mercury menu and proposed Gemini food is shown in Table I.

## Bioinstrumentation

The physiological parameters measured during Astronaut Cooper's flight consisted of two-channeled electrocardiogram-respiration, blood pressure, and oral body temperature. The basic bioinstrumentation has been described previously (2, 3, and 4). Therefore, only those modifications to this basic instrumentation are presented. Body temperature measurements in the earlier manned flights utilized a rectal thermistor sensor. In the last Mercury flight, this was replaced by an oral probe which the astronaut utilized on ground command. When not in use this temperature probe was attached to the astronaut's communication ear cup and thus gave a readout of space suit ventilation gas exit temperatures. The biomedical results of this final Mercury flight will be published presently (5).

## Atmospheric Instrumentation

The measurement of oxygen and carbon dioxide partial pressures in the Mercury flights was a problem. Satisfactory sensors for measuring oxygen and carbon dioxide partial pressure were developed for the Cooper flight. The early oxygen partial pressure sensors utilized a polarographic method of determining oxygen concentration. The major problem with these sensors was the short shelf life, that is, the electrolyte dried out if it was not maintained in a rigidly controlled atmosphere. This characteristic posed serious operational problems in servicing on the launch pad. The carbon dioxide partial pressure sensor developed for Cooper's flight utilized a glass electrode type sensor which was a modification of a laboratory pH sensor. Both the oxygen and the carbon dioxide sensors performed satisfactorily in this flight.

## Space Suits

The space suit used by Cooper was a refined model of those previously used in the Mercury flights (fig. 5). Throughout the Mercury project continuing development program was conducted to provide space suits utilizing the latest technological advances compatible with the constraints imposed by the spacecraft configuration and mission. Such features as the glove lights for illuminating the instrument panel, a urine collection and transfer system, an improved shoulder construction to provide increased upper torso mobility, and a mechanical visor seal are examples of product improvement which was accomplished. The Mercury space suit was flown only as a cabin pressure backup. It was necessary to provide sufficient arm and shoulder mobility to permit the astronaut to perform control tasks while pressurized. The Gemini space suit development program is based on the Mercury design and flight experience and a critical review of those requirements peculiar to the Gemini program. The Gemini suit problems include long term habitability, mobility, and comfort. An effort has been made to reduce the number of suit service connections and the helmet has been designed without exterior connections. The Apollo space suit development program has as its prime objective the requirement to support a man on the lunar surface for scientific exploration. The space suit assembly will consist of the suit, portable backpack life support system, power supply, and communications systems. The suit must provide total body mobility and comfort and thermal protection against the lunar environment. The suit will be utilized onboard the spacecraft during critical flight phases to provide protection in the event of cabin decompression. More complete information on the suit development programs is contained in reference 6.

## III. Physiological Design Criteria

The increase in flight mission time and the ever present need for providing life support and crew protective systems at the minimum weight and volume have required the physiologist to establish better design criteria with respect to human tolerance and performance to assist in spacecraft and system detailed design. This area of work includes acceleration, noise, vibration, atmospheric composition and pressure, metabolic and thermal balance, and nutrition. Many varied physiological research programs are currently underway to establish or validate the design goals for Gemini and Apollo. A few examples of these programs are presented to illustrate the scope of this effort.

## Human Tolerance to Impact Loads

Current spacecraft basically utilize a high drag reentry with a parachute landing system. This type of system, inherently requires that the spacecraft land at a relatively high vertical velocity. Under the constraints of these landing loads it is essential that the crewmen be provided with an adequate body support system in which the landing loads are reduced to the lowest level consistent with risk of injury and weight considerations. In the Mercury spacecraft program an impact bag device was developed to attenuate the landing loads to permit safe ground landings. This development resulted in a considerable weight penalty. Since the Apollo spacecraft is to employ a parachute recovery system similar to Project Mercury, it became apparent at the start that human tolerance to impact should be more precisely defined to preclude an excessive weight penalty for landing load attenuation. A program was therefore established to define human tolerance for transverse, lateral and resultant impact landing loads. The results of this effort have been previously presented (7). Three laboratories cooperated in this joint effort. In this program common support and restraint systems, instrumentation systems and test conditions were established. Each laboratory conducted tests in one area of study with some overlap for correlation. At the completion of these tests each individual investigator's work could be evaluated on a common basis so that mission limits could be established. Figure 6 summarizes the results of this study. Considering a man in the supine position, the envelope of the acceptable impact forces may be described as a 15g cylinder having a 20g (EBI or + $G_x$) spherical cap. For essentially forward acting forces, the limits are 20g. For lateral, headward, and tailward acting forces, the limits are 15g. Specific rates of onset (rate of application of g) are associated with these limits also. For forward acting forces, the allowable rate of onset is 10,000g per second; for lateral acting forces, 1,000g per second; and for headward and tailward acting forces 500g per second. For the intermediate 45° directions having a forward acting component, the rate of onset may be 1,000g per second also.

The limits described are valid only for the range of variables indicated. Velocity changes, rise times, and direction of applied forces, must be within the limits indicated. The restraint and support systems must be similar in principle to that shown by Figure 7. The head, shoulders, and pelvis must be supported laterally by essentially rigid structure. The depth of the lateral supports in the front-to-back direction should be such that the subject's body cannot roll up and over the sides. The restraint harness should thoroughly restrain the subject's chest, pelvis, and thighs.

## Gaseous Environment Selection

The selection of the optimum atmosphere for spacecraft use which would be compatible with operational requirements, physiological considerations, weight penalties and system reliability, has been a continuing program in the NASA Manned space flight program. The Mercury spacecraft utilized a nearly pure oxygen atmosphere at a pressure of 5 psia. The Gemini and Apollo spacecraft likewise will utilize this atmosphere. Early in the development phase of the latter two flight projects it became apparent that the physiologist must better define the effects of long term exposure to an atmosphere of pure oxygen at a pressure of 5 psia. It was felt that if there were no compelling physiological contraindications to the use of a single gas system, the overall mission reliability would be increased. The rationale behind this statement was: (1) the use of a two-gas system in a spacecraft from which extra-vehicular operation would take place might result in dysbarism or perhaps increase the time for a crewman to go from shirtsleeve environment consisting of two gases to space suit operation with oxygen at a pressure of 3.5 psia, and (2) the use of a single gas system reduces several complicated system control components essential for the operation of a two-gas system.

In order to ascertain that the single gas system of 100 percent oxygen at a pressure of 5 psia did not present physiological limitations for flight missions of 14 days, a program was formulated wherein human volunteers were subjected to this gas. Several organizations were asked to conduct these studies. A portion of the program was conducted under static conditions within low pressure chambers. Others were conducted that included the dynamic features of the mission, by inducing the launch and reentry acceleration profiles at the beginning and end of the 14-day duration, respectively. The results of this series of tests revealed no physiological reason why a single gas system should not be utilized for the time period being considered.

## IV. Biomedical Aspects

Two principal problem areas presently command our attention regarding the biomedical or physiological effects of prolonged space flight. These potential hazards relate to the cardiovascular and musculoskeletal systems of the astronaut.

### Cardiovascular Considerations

The cardiovascular responses of the Mercury astronauts during and following the dynamic phases of the first three orbital flights are published and familiar data, (2,3,4) and the results of Cooper's 34-hour flight are soon to be released (5). In general, lift-off and reentry are attended by a slight to moderate increase in blood pressure and heart rate, with a resumption of "normal" or control values during orbital flight. (Tables II and III). The later flights of longer duration, however, have been attended by unmistakable signs of postural hypotension observed in the astronaut during the early recovery period.

Following the 9-hour 12-minute MA-8 flight of Schirra, an increased lability of blood pressure and pulse rate was noted coincident with postural changes. Thus, when supine, the pulse rate averaged some 70 beats per minute, increasing immediately to 100 or greater on standing.

The accompanying blood pressure changes were less dramatic, but there was nonetheless a significant drop in systolic pressure on standing. No apparent change in the diastolic pressure was observed. In addition, marked venous stasis was evidenced in the dependent (lower) extremities during the postflight period. Schirra sustained a weight loss of $4\frac{1}{2}$ pounds with an hematocrit rise of 3 points (44 to 47). Thus, dehydration and probable concomitant hypovolemia were doubtless contributing factors in this episode of postural hypotension.

In view of these and other data, it would seem patently evident that the prolonged weightless state has a fundamental and profound effect on the cardiovascular homeostatic mechanisms in man, and that this effect is potentiated by dehydration and hemoconcentration or hypovolemia

This area is currently under intensive investigation in normal healthy humans subjected to strict immobilization for varying periods of time. These studies represent a concerted effort to define more precisely the basic etiology of the observed postural hypotension phenomenon, the contributing endocrine and fluid balance factors, and the indicated remedial measures. It is tempting to postulate a "physiological disuse atrophy" of venomotor reflexes as a consequence of prolonged exposure to the hypogravic environment. Thus, on return to force-fields, there is a diminished competence of the cardiovascular system to maintain adequate blood pressure, presumably a manifestation of venous dystonia and pooling resulting in inadequate venous return, diminished cardiac output, diminished blood pressure, and the resultant inadequate perfusion of the cerebrum.

Other current research programs are directed toward examining the physiological factors of orbital flight as compared with competitive athletic events and similar stressful situations such as football, sports car racing, ice hockey, polo, crew, and sky-diving. Preliminary data obtained at a sports car racing event indicate that these competitions are considerably more taxing to the cardiovascular system than are earth-orbiting flights. Thus, telemetered physiological data from expert sports car racers during a recent national competition, revealed a mean pulse rate of approximately 200 with a respiration rate of 42 in certain individuals. This occurred during a 60 lap event lasting 90 minutes with an average speed of 83.5 mph over an irregular course (Watkins Glen, New York). Comparison of these data with those of the astronauts during launch, orbital flight, and reentry (2,3,4) indicates that space flight is not nearly so demanding of the cardiopulmonary system of man as are endurance athletic contests such as sports car racing.

Further, the capacity of the human organism to do sustained work or exercise under hypogravic conditions does not appear to be diminished. In fact, exercise during orbital flight with the astronaut utilizing a timed-measured workload would appear to be significantly less taxing both subjectively and objectively. Table IV indicates the pulse rate and blood pressure changes resulting from an in-flight workload of 60 foot pounds per second for a 30 second period of time. There was a somewhat higher mean pulse rate during exercise under weightless conditions than during the preflight control runs, and somewhat higher blood pressure values were registered. In addition, the mean pulse rate remained elevated for a longer period of time following the in-flight exercise period. Subjectively, the pilots reported that the actual performance of the exercise in the gravity-free state was less fatiguing, less of an exertion or effort than were the control ground runs. Admittedly, these workloads are not excessive in terms of weight or duration of effort, but they do provide some information regarding the ability of the astronaut to perform physical tasks, and further provide some insight into the physiological aspects of this in-flight effort. Future experiments will endeavor to determine the effects of greater and more sustained effort on various physiological parameters following more lengthy periods of weightlessness.

### Musculoskeletal Considerations

Another major area of physiological concern during extended space flights relates to anticipated muscle atrophy and bone demineralization during prolonged exposure to weightlessness. The Mercury data (2,3,4) thus far obtained indicate that in the relatively short flights, at least, no significant mobilization of nitrogen or calcium occurred. Extensive research programs are now in progress whose aim is to define optimal isometric exercise regimens and dietary requirements which will prevent, or mitigate to a great extent, the nitrogen and calcium losses anticipated during lengthy space flights. Data from current immobilization studies of earth-based specimens suggest that these changes are reversible and indeed can be inhibited or markedly reduced by appropriate remedial exercises and dietary considerations.

## V. Summary

The Mercury environmental control system provided a satisfactory method for the control of the gaseous environment for flights up to

34 hours. Problems were encountered in thermal control. The other Mercury life support systems including space suits, food, water, and instrumentation, are providing a strong base on which the Gemini and Apollo systems are being developed. Many varied programs in better defining physiological design requirements are underway to insure proper system designs consistent with weight and volume considerations. Ground-based and flight medical experimental programs are being pursued to provide a better understanding of the problems associated with weightlessness and the physiological cost of high stress.

# REFERENCES

1. Johnston, Richard S.: "Mercury Life Support Systems for Space Vehicles." (Presented at the IAS 28th Meeting, New York, Jan. 25-27, 1960) SMF Fund Paper No. FF-25.

2. NASA Manned Spacecraft Center, Results of the First United States Manned Orbital Space Flight, February 20, 1962.

3. NASA Manned Spacecraft Center, Results of the Second United States Manned Orbital Space Flight, May 24, 1962.

4. NASA Manned Spacecraft Center, Results of the Third United States Manned Orbital Space Flight, October 3, 1962.

5. NASA Manned Spacecraft Center, Results of the Fourth United States Manned Orbital Space Flight (to be published).

6. Correale, James V., Guy, Walter W.: "Space Suits." (Presented at the 129th Annual Meeting of the American Association for Advancement of Science, Philadelphia, Pennsylvania, December 30, 1962.)

7. Pesman, G. J., Scherer, H. F.: "Extension of the Measured Experience of Human Impact Loads." (Presented at the 34th Annual Scientific Meeting of the Aerospace Medical Association, Los Angeles, California, April 29 - May 2, 1963.)

8. Michel, Edward L., Smith, George B., Jr., M. D., Johnston, Richard S.: "Gaseous Environment Considerations and Evaluation Programs Leading to Spacecraft Atmosphere Selection." (Presented at the 34th Annual Scientific Meeting of the Aerospace Medical Association, Los Angeles, California, April 29 - May 2, 1963.)

TABLE I.- FOOD WEIGHT AND VOLUME COMPARISON
IN PROJECT MERCURY TO PROJECT GEMINI

| To Provide 2,500 Calories | | |
|---|---|---|
| Req: | Mercury | Gemini |
| Foods: | 12 tubes pureed foods | 8 bags rehydratable foods |
| | 6 roll malted milk tablets | 10 dispensing wraps of bite size ready-to-eat foods |
| Weight: | 4.4 pounds | 1.3 pounds |
| Volume: | 191 cubic inches | 100 cubic inches |

TABLE II.- SUMMARY OF PREFLIGHT DATA

| Event | Pulse Rate Beats/Min Range | Mean | Blood Press MM Hg | Resp/Min | Body Temp °F |
|---|---|---|---|---|---|
| Attempted Launch Jan 27 | 60 to 88 | 70 | | 12 to 20 | 99 |
| Transfer Van MA-6 | 58 to 82 | 72 | 122/77 | 20 | 99.2 |
| Countdown MA-6 | 56 to 86 | 68 | Mean 123/87 | 20 | 98.6 to 97.6 |

TABLE III.- SUMMARY OF FLIGHT DATA

| EVENT | PULSE RATE BEATS/MIN | BLOOD PRESS MM Hg | RESP RATE BREATHS/MIN | BODY TEMP °F |
|---|---|---|---|---|
| Lift-off period (Maximum) | 110 | | 14 | 97.6 |
| Spacecraft Sep. | 114 | | 12 | 97.6 |
| Weight-lessness | Mean 86 | Mean 129/70 | 8 to 14 | 98.6 |
| Retrofire | 96 | | 12 | 99.2 |
| Reentry Period (Maximum) | 134 | | 19 | 99.3 |
| Biosensor Disconnect | 104 | | 16 | 99.5 |

TABLE IV.- IN-FLIGHT EXERCISE

| Calibrated Workload | Mean Heart Rate | Mean Blood Pressure |
|---|---|---|
| | PREFLIGHT (5 determinations) | |
| Prework | 74 | 104/81 |
| Work | 115 | -- |
| Postwork | 85 | 111/79 |
| | FLIGHT (2 determinations) | |
| Prework | 89 | 117/77 |
| Work | 131 | -- |
| Postwork | 106 | 124/95 |

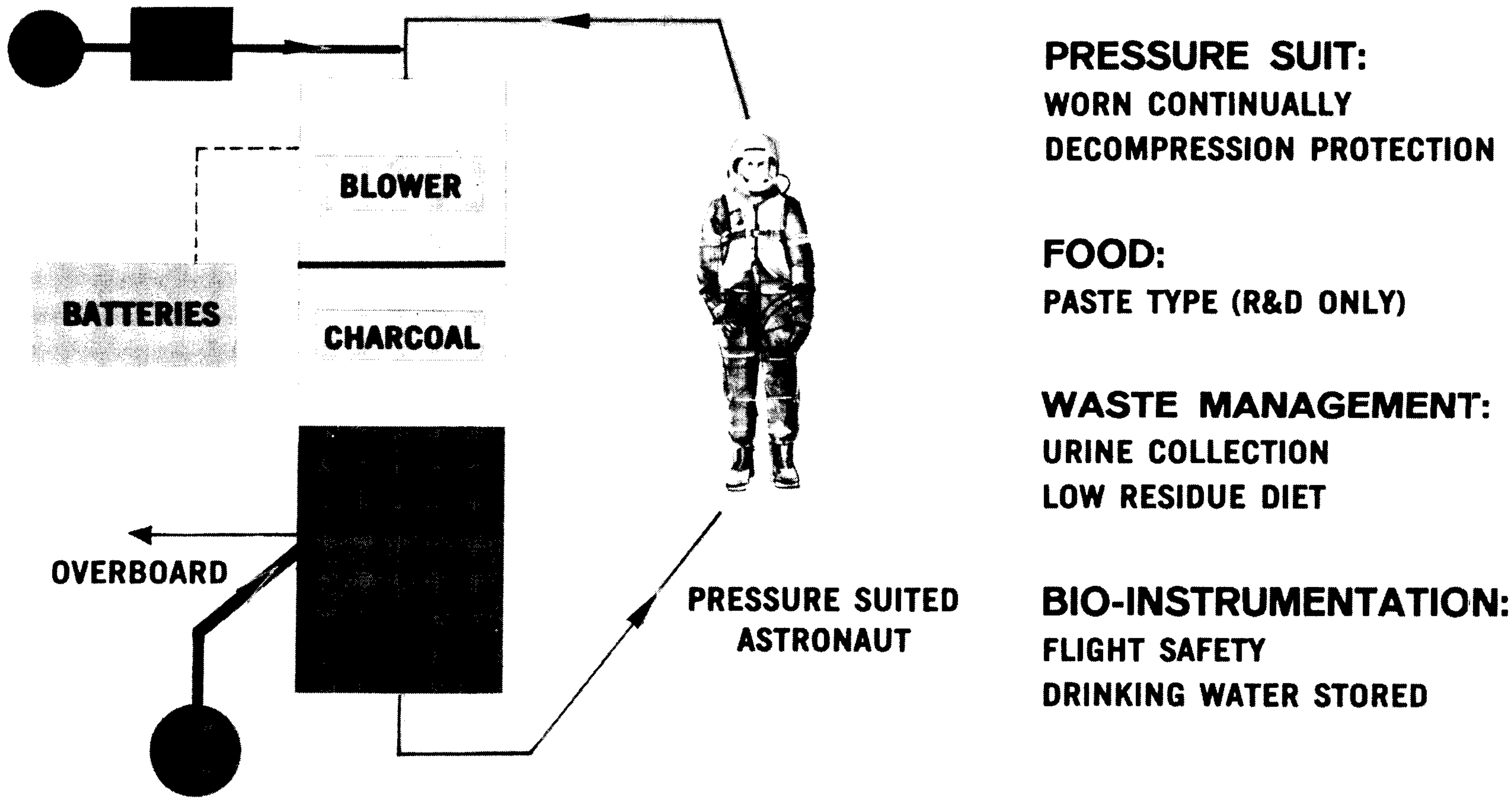


Figure 1. Mercury Life Support System

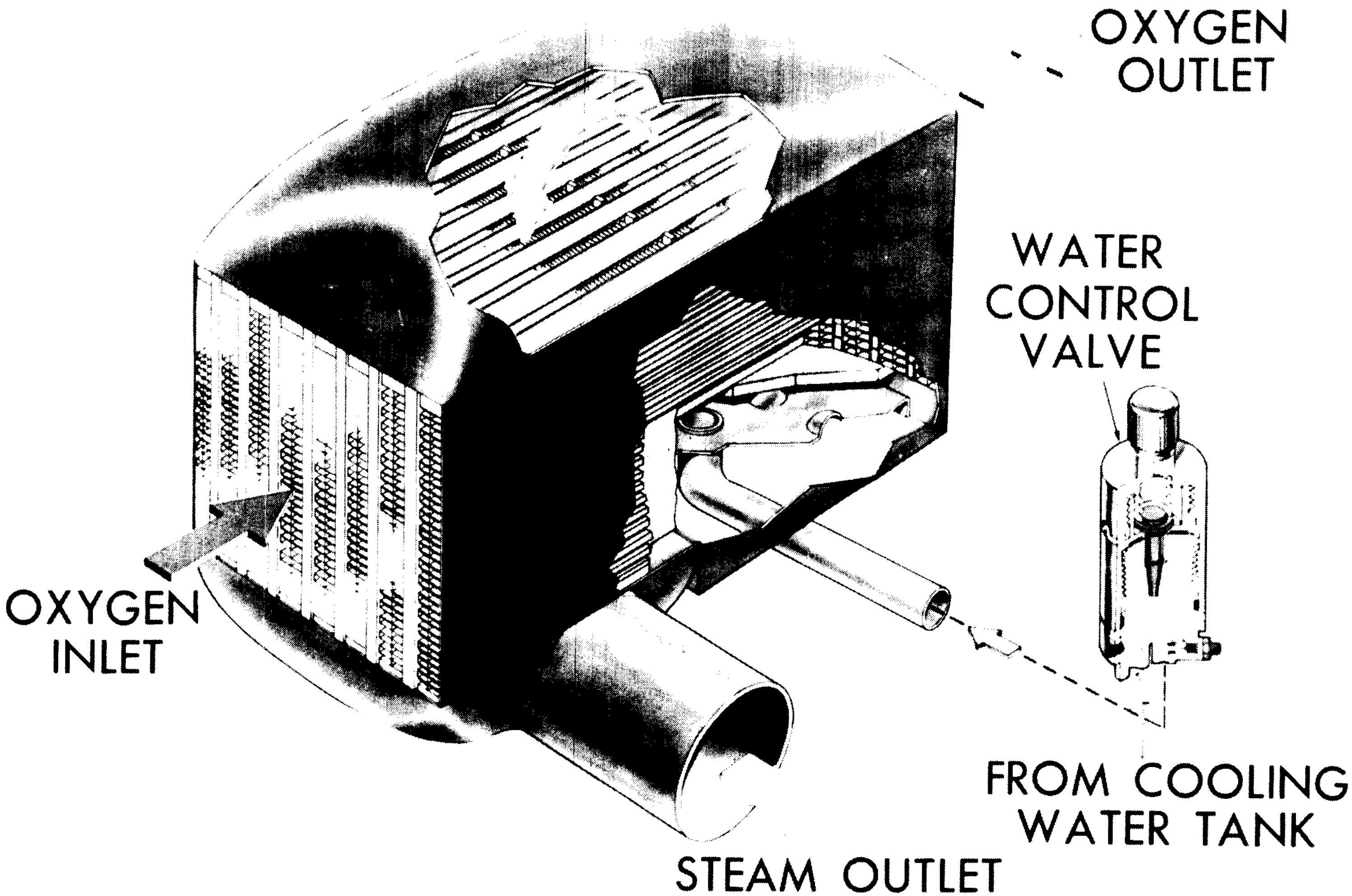


Figure 2. Mercury Type Heat Exchanger

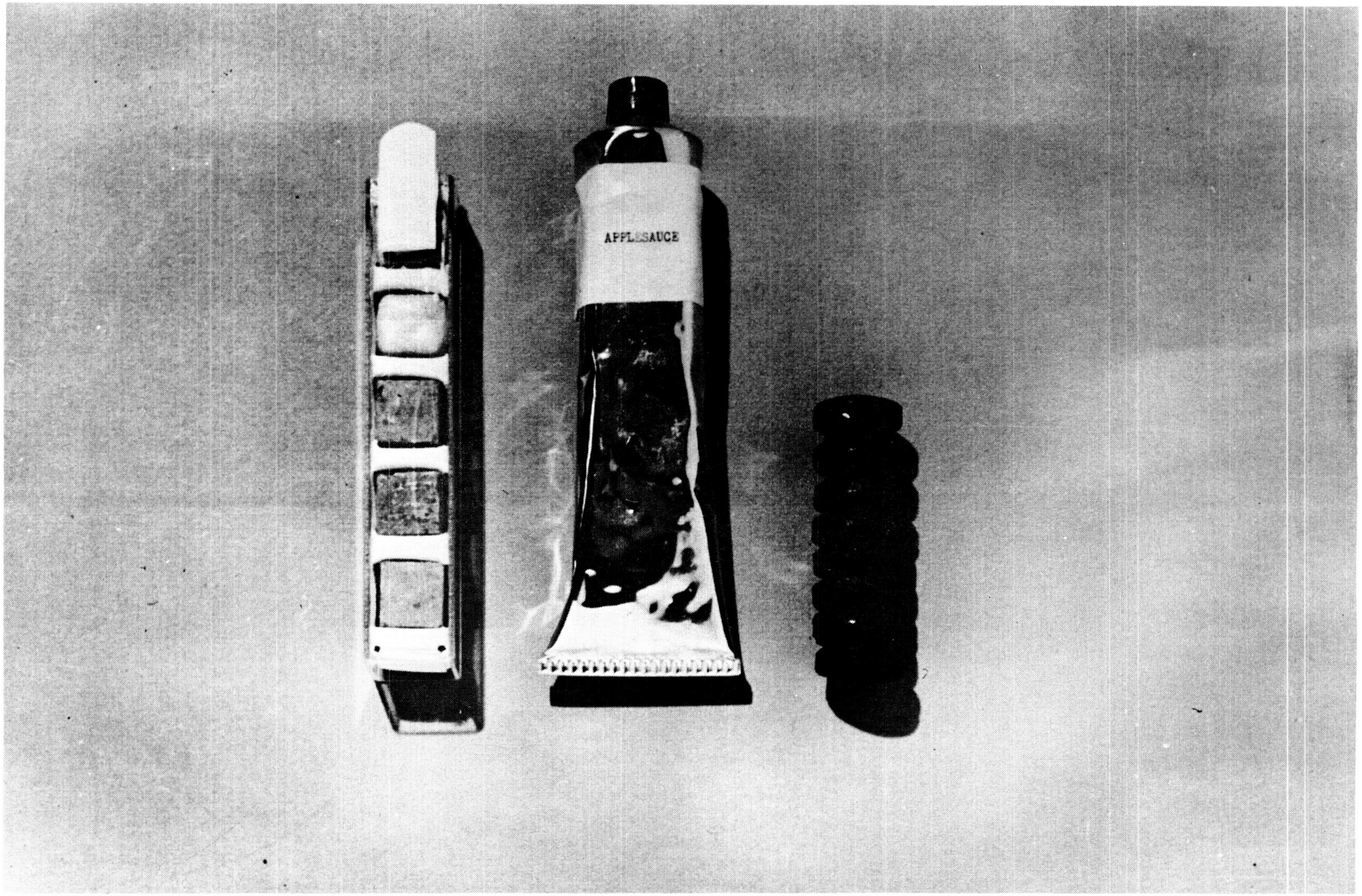


Figure 3. Original Mercury Food Provisions

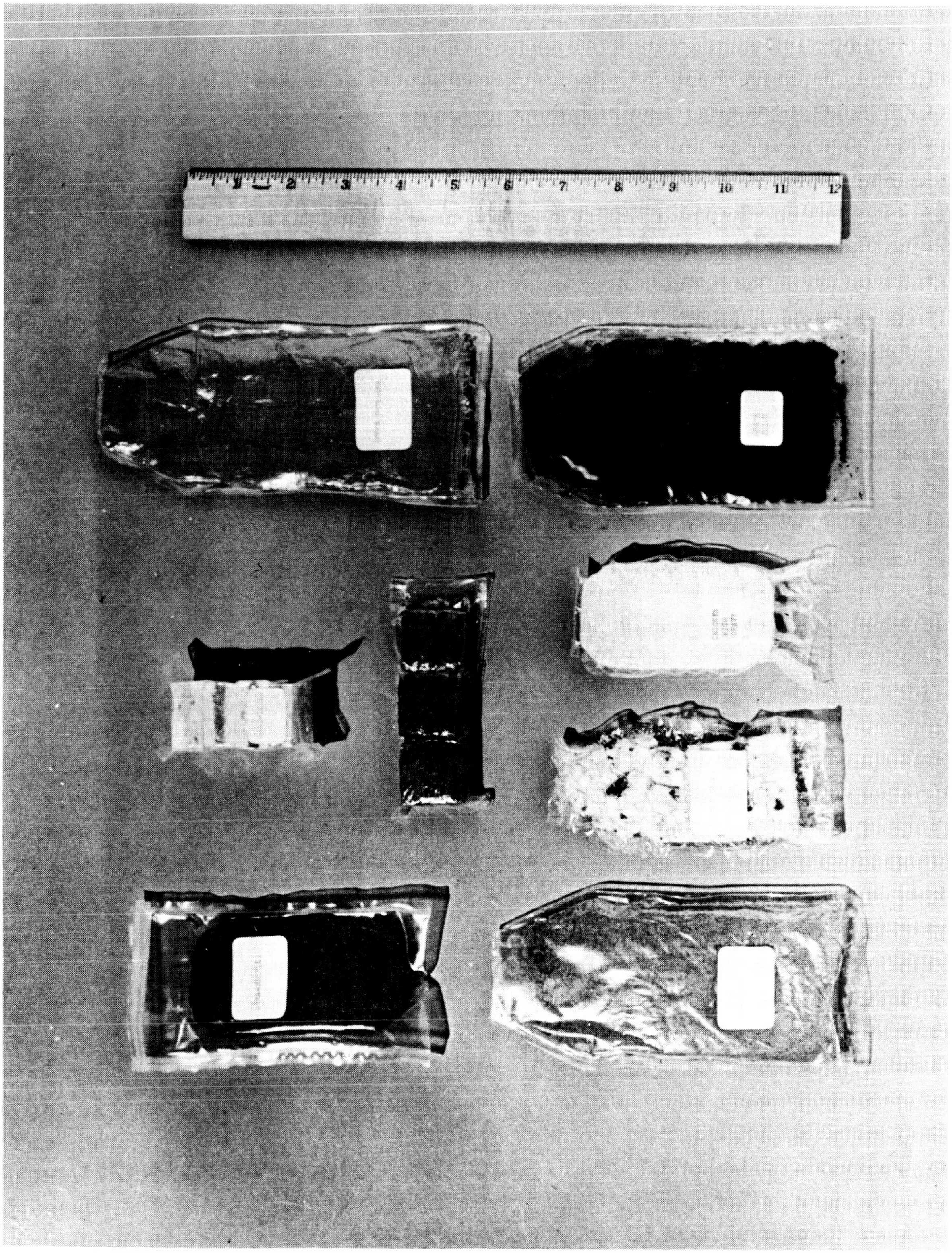

Figure 4. Gemini Type Freeze-Dried Foods

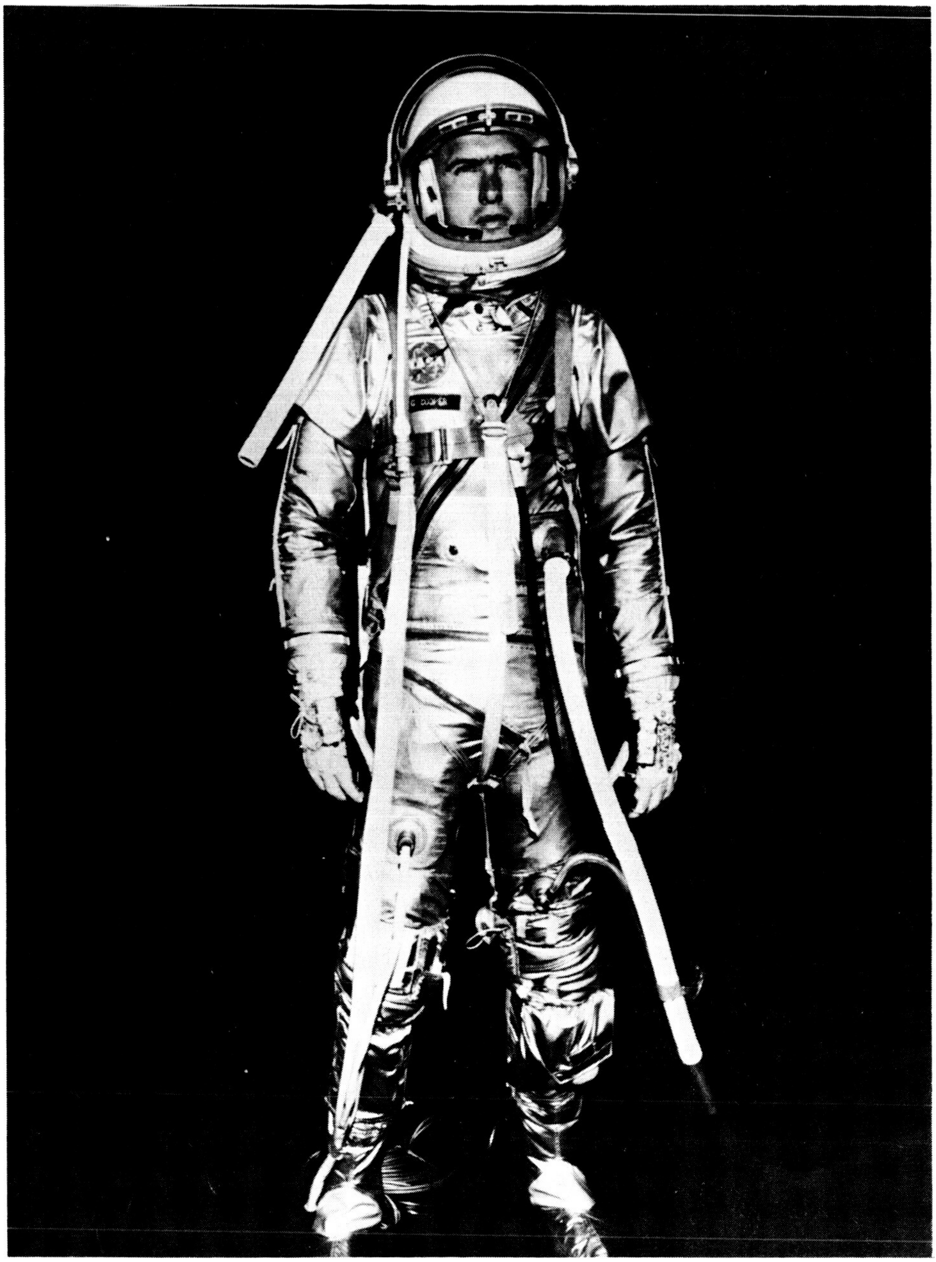

Figure 5. Mercury Space Suit

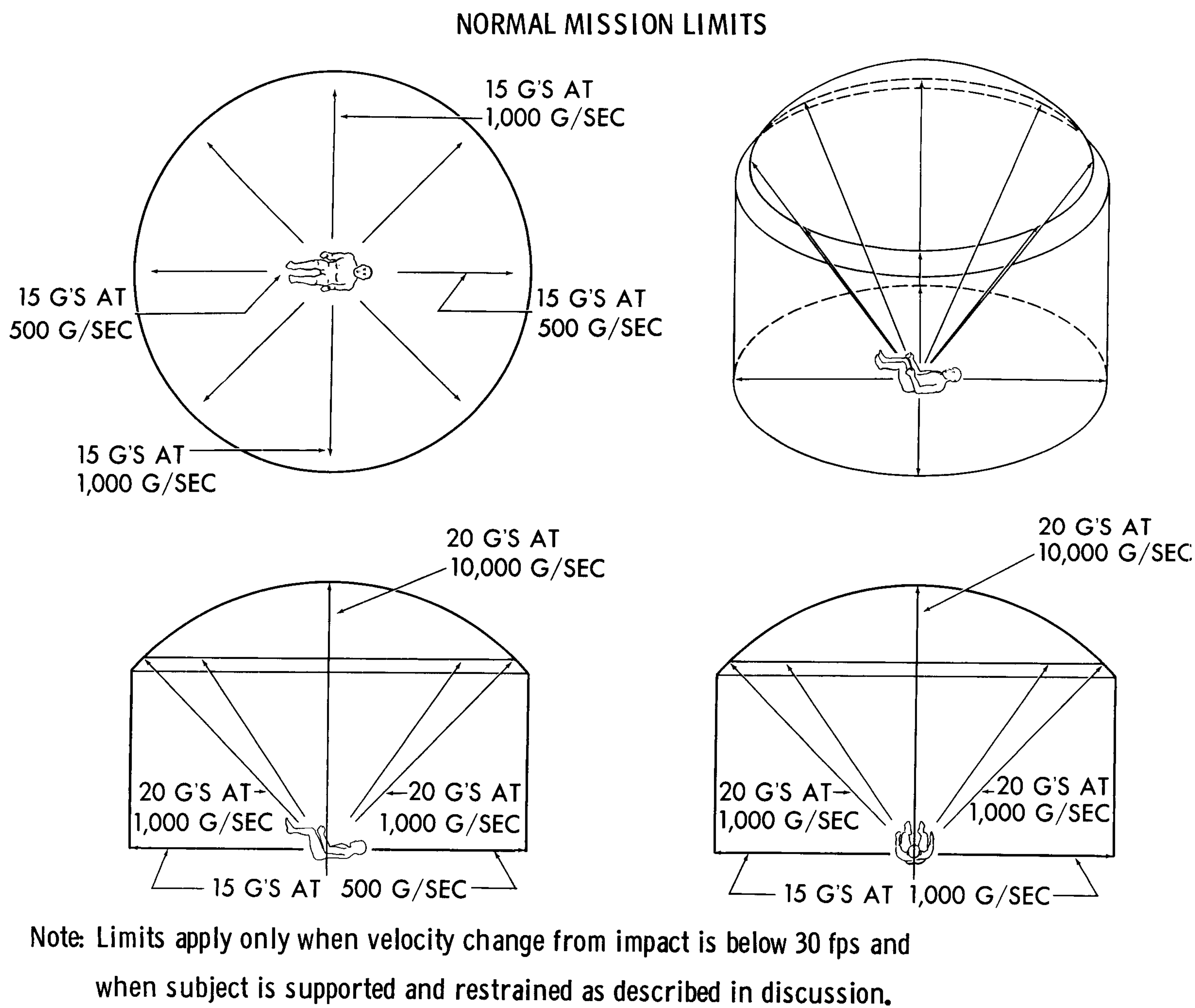


Figure 6. Normal Mission Limits

# ILLUSTRATION OF RESTRAINT & SUPPORT

Figure 7. Illustration of Support and Restraint